Contract # N00014-14-C-0020

Pilot-in-the-Loop CFD Method Development

Progress Report (CDRL A001)

Progress Report for Period: April 1, 2014 to May 20, 2014

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Section I: Project Summary

1. Overview of Project

This project is performed under the Office of Naval Research program on Basic and Applied Research in Sea-Based Aviation (ONR BAA12-SN-0028). This project addresses the Sea Based Aviation (SBA) virtual dynamic interface (VDI) research topic area "Fast, high-fidelity physics-based simulation of coupled aerodynamics of moving ship and maneuvering rotorcraft". The work is a collaborative effort between Penn State, NAVAIR, and Combustion Research and Flow Technology (CRAFT-Tech). This document presents progress at Penn State University.

All software supporting piloted simulations must run at real time speeds or faster. This requirement drives the number of equations that can be solved and in turn the fidelity of supporting physics based models. For real-time aircraft simulations, all aerodynamic related information for both the aircraft and the environment are incorporated into the simulation by way of lookup tables. This approach decouples the aerodynamics of the aircraft from the rest of its external environment. For example, ship airwakes are calculated using CFD solutions without the presence of the helicopter main rotor. The gusts from the turbulent ship airwake are then re-played into the aircraft aerodynamic model via look-up tables. For up and away simulations, this approach works well. However, when an aircraft is flying very close to another body (i.e. a ship superstructure), aerodynamic coupling can exist. The main rotor of the helicopter distorts the flow around the ship possibly resulting significant differences in the disturbance on the helicopter. In such cases it is necessary to perform simultaneous calculations of both the Navier-Stokes equations and the aircraft equations of motion in order to achieve a high level of fidelity. This project will explore novel numerical modeling and computer hardware approaches with the goal of real time, fully coupled CFD for virtual dynamic interface modeling & simulation.

Penn State is supporting the project through integration of their GENHEL-PSU simulation model of a utility helicopter with CRAFT-Tech's flow solvers. Penn State will provide their piloted simulation facility (the VLRCOE rotorcraft simulator) for preliminary demonstrations of pilot-in-the-loop simulations. Finally, Penn State will provide support for a final demonstration of the methods on the NAVAIR Manned Flight Simulator.

2. Activities this period

The flight dynamics software used in the project is the GENHEL-PSU simulation code. This code is a non-linear dynamic model of a utility helicopter with a blade element rotor and finite state inflow model. The code can easily operate in real-time simulations (i.e. real-time execution of the code is not a major factor). However, the code needs to be set up to integrate with the fast flow solvers being developed at CRAFT-Tech. Efficient integration and data exchange between the flight simulation (GENHEL-PSU) and the flow solver (CRUNCH) will be critical to achieve fast execution speeds and eventually real-time.

During this period of report, the GENHEL-PSU code has been ported to a Linux platform in order to more readily integrate with the CRUNCH flow solvers that will be used in coupled simulations. For initial testing, one-way coupled simulations were set up. The one-way coupled airwake model had been developed in previous efforts at Penn State [1], but had not been used in several years, so it needed to be debugged and verified with the latest version of GENHEL-PSU. The airwake module was activated and verified with one-way coupled LHA class ship airwake CFD results, produced by PUMA2 CFD code at Penn State[1].

Porting GENHEL-PSU to a Linux platform process started with choosing an appropriate Linux distribution and compiler tools. CentOS Linux distribution has been chosen as a Linux platform and Intel Fortran and GNU GCC compilers have been chosen as main compilation tools. The porting process required that most of the communication libraries (required for the future tasks of this project) to be written partially or fully again. The code was successfully ported and the outputs of the Linux version were verified against the GENHEL-PSU Windows Version.

		
(a)	(b)	(c)

Figure 1: a) CentOS 6.5 has been chosen as an operating platform. **b)** Intel Fortran Compiler tool for Fortran code. **c)** GNU GCC Compiler has been used for C/C++ code compilation

The airwake module of GENHEL-PSU runs as a separate code for integrating external CFD ship airwake data from a lookup table with GENHEL helicopter simulation results via network sockets. This code writes the ship airwake data to a memory block shared with GENHEL-PSU and this data is used as gust perturbations during helicopter flight dynamics calculations by GENHEL. Figure 2 shows the GENHEL-PSU / Airwake module data interface schema.

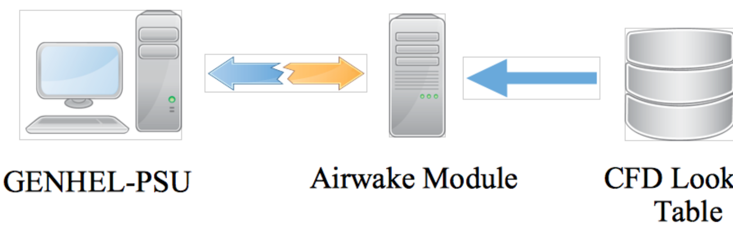

Figure 2: GENHEL-PSU / Airwake Module Interface Schema

In initial tests, the airwake module used LHA-5 ship airwake solutions produced by the PUMA2 CFD solver at Penn State. These simulations were used to test and verify the Linux Version of GENHEL-PSU and Airwake code. The stored airwake data provides a time-varying velocity field on a domain which is located over the rear deck of LHA ship as shown in Figure 3.

The GENHEL-PSU simulation was performed with a non-linear dynamic inversion control law developed in recent work at PSU [2]. This controller achieves high precision closed-loop control of the simulated helicopter and holds its position over the ship deck with tolerances less than 10 ft. Note that this controller will be useful in future coupled simulations, since non-real-time simulations need a “pilot model” to regulate the helicopter (which has unstable dynamics) and keep it in a fixed location within the airwake.

Time-history results of X-Y-Alt positions (ft), attitude angles(deg) and gust velocity components(ft/sec) are shown in Figure 4-6 for the simulated helicopter hovering over landing spot 8 on the LHA ship in 30 knot, 0 degree wind-over-deck conditions. Results compare the case with and without an airwake. As seen, the controller holds the position over the deck (within 4 ft of the original position), and the airwake has a time-varying disturbance on the helicopter (as seen by the larger attitude and position fluctuations with the airwake).

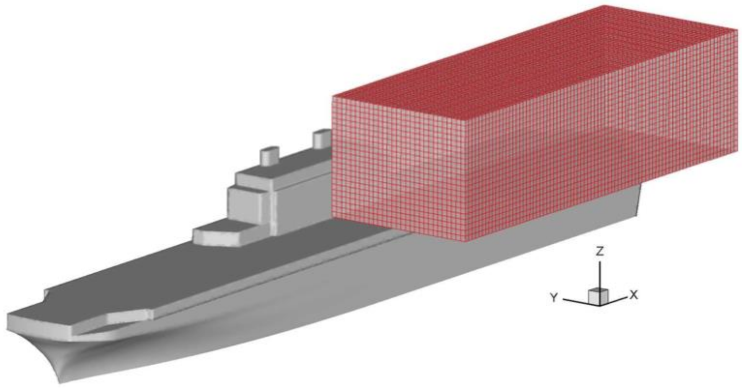

Figure 3 : Rectangular volumetric domain of CFD data at the rear deck of LHA for DI simulations (from [1])

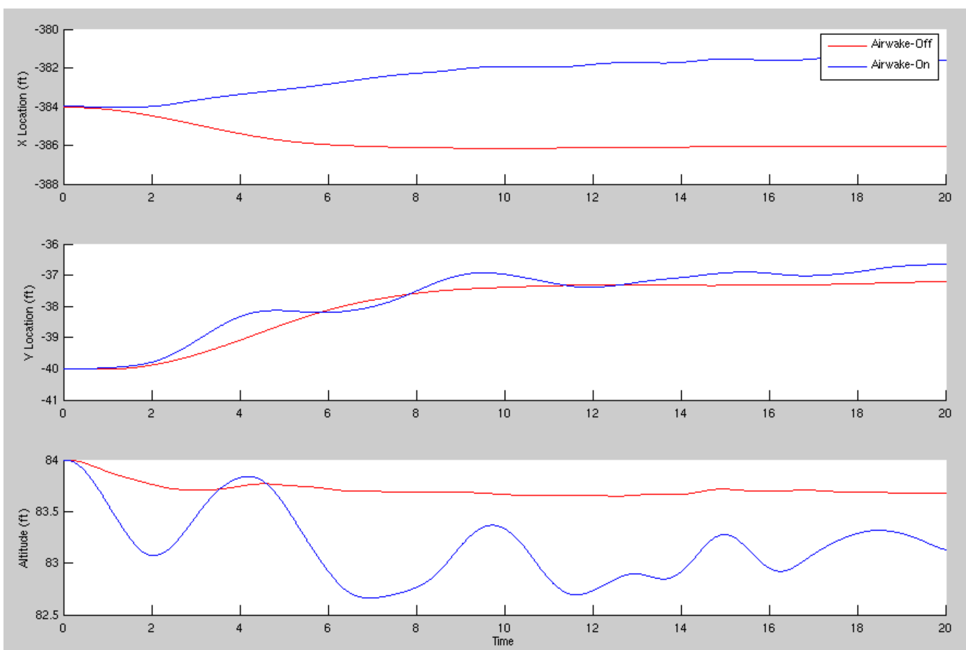

Figure 4 : Variation in position of UH-60 Helicopter with TRC(Transitional Rate Command) Controller-On.

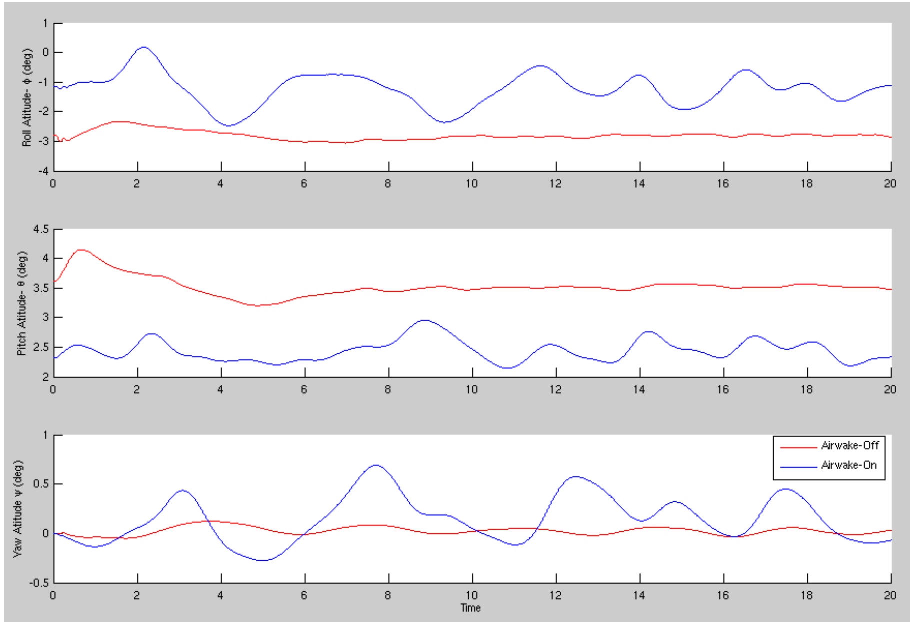

Figure 5: Attitude response of UH-60 Helicopter with TRC(Transitional Rate Command) Controller-On

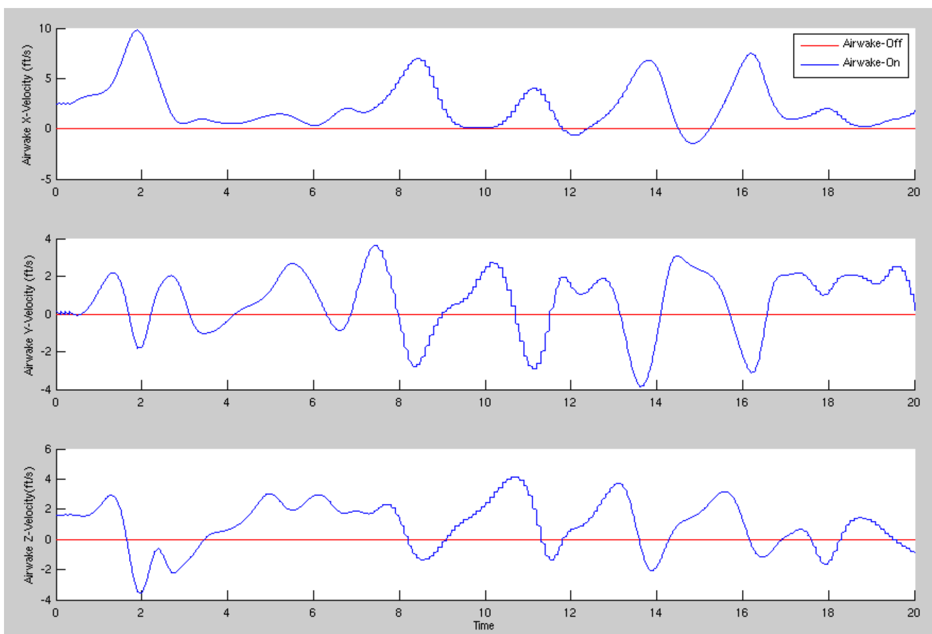

Figure 6: Change in gust velocity components applied to aircraft during simulation

CRAFT Tech has provided the CRUNCH-CFD software, documentation and licenses for the clusters at Penn State. A video conference has been held between Penn State and CRAFT Tech researchers to go over CRUNCH CFD GUI and to speed up the learning curve of the software. Several CRUNCH-CFD Tutorials has been provided by CRAFT Tech to the Penn State to get familiar with the software and the ship airwake CFD analysis.

Coupled simulations will be run at PSU on the COCOA-4 cluster, a high performance computing cluster. The CRUNCH CFD software has been installed on the COCOA-4 servers and initial software tests are being conducted. Initial efforts will use the Generic Frigate Shape SFS-2 to perform CFD solutions for one-way coupled simulations [3]. Figure 7 shows the CRUNCH GUI with the generic frigate model.

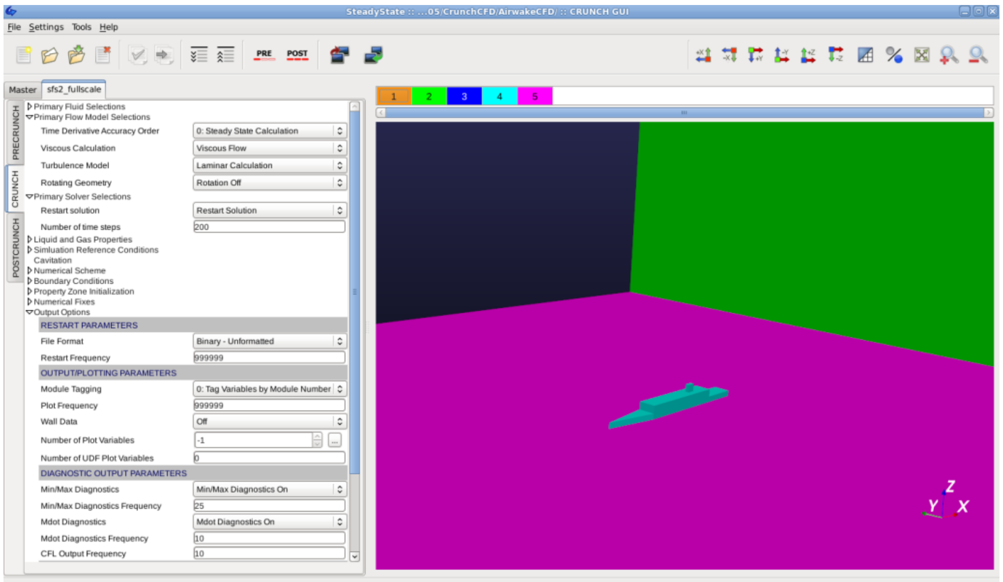

Figure 7: A view from CRUNCH-CFD GUI with SFS-2 Grid

3 Significance of Results

The two months devoted primarily to student training and setting up tools for the research. The student is now trained on using GENHEL-PSU and the CRUNCH software. All of the tools are place at Penn State for performance of the research tasks.

4 Plans and upcoming events for next reporting period

- Perform time-varying flow solutions of SFS-2 Generic Frigate shape.
- Integrate these flow solutions with GENHEL-PSU and develop a set of baseline simulations of the utility helicopter operating in a ship airwake with one-way coupled flow solutions. This will provide a baseline with which to compare the fully coupled solutions.
- Begin development of fully-coupled simulations: In fully coupled solutions, blade position and aero loads are transmitted to the CFD code, the CFD code then calculates a velocity field (including the induced velocities from the aircraft airloads) and sends these velocity values back to the helicopter simulation model. The subsequent airloads and dynamics of the helicopter are then affected by the evolving external flow field. In this sense, the CFD solutions serve the purpose of not only the ship airwake effects but of the induced flow field generated by the helicopter main rotor (and possibly other components of the aircraft). Induced flow in the rotor is usually modeled by a lower order model in flight simulations (e.g. finite state inflow), but these modules will be replaced by CFD in the coupled solitions.
- Initial coupled solutions will not involve ship flow fields. Coupled simulations will be performed with the helicopter hovering in an open domain. The helicopter will be trimmed and perform an extended hover using the controller. The performance and trim of the helicopter will be compared to those predicted by the simulation model without coupled CFD. We expect to begin development of these solutions in June, with results expected later this summer.

5 References

1. Lee D., Sezer-Uzol, N., Horn, J.F., and Long, L.N., “Simulation of Helicopter Shipboard Launch and Recovery with Time-Accurate Airwakes,” The American Helicopter Society 59th Annual Forum, Phoenix, AZ, May 2003.
2. Soneson, G.L., and Horn, J.F., “Simulation Testing of Advanced Response Types for Ship-Based Rotorcraft,” Proceedings of the American Helicopter Society 70th Annual Forum, Montreal, Canada, May 2014.
3. Zhang F., and Xu. H., “Numerical Simulation of Unsteady Flow over SFS 2 Ship Model,” AIAA-2009-0081, 47th Aerospace Sciences Meeting, Orlando, FL, Jan. 5-8, 2009.

6 Transitions/Impact

No major transition activities during the first quarter of the project.

7 Collaborations

Penn State has collaborated with CRAFT-Tech as described above.

8 Personnel supported

Principal investigator: Joseph F. Horn

Graduate Students: Ilker Oruc, PhD Student

9 Publications

No publications to date.

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